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THE AERODYNAMIC DAMPING AND OSCILLATORY STABILITY IN PITCH OF TWO HIGH-DRAG BODIES OF REVOLUTION AT TRANSONIC SPEEDS

by Robert A. Kilgore and Richard L. Braslow

Langley Research Center

Langley Station, Hampton, Va.

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THE AERODYNAMIC DAMPING AND OSCILLATORY STABILITY IN PITCH OF TWO HIGH-DRAG BODIES OF REVOLUTION AT TRANSONIC SPEEDS*

By Robert A. Kilgore and Richard L. Barton

SUMMARY

Wind-tunnel measurements of the aerodynamic damping and oscillatory stability in pitch of two high-drag bodies of revolution have been made at Mach numbers M from 0.60 to 1.20 by using a forced-oscillation technique. Tests were made at an oscillation amplitude of about 2° at mean angles of attack α from -4° to 14°.

Near $\alpha = 0^{\circ}$ both configurations had negative damping in pitch. Away from $\alpha = 0^{\circ}$ both configurations had nearly zero damping at a Mach number of 0.60 and slightly positive damping at the higher Mach numbers.

Both configurations had almost constant positive oscillatory stability over the α range of the same magnitude except at $M = 0.60$, for which configuration 1 was more stable than configuration 2 at the same Reynolds number. A decrease in Reynolds number for configuration 1 decreased its stability to the same level as that obtained with configuration 2 at the higher Reynolds number.

INTRODUCTION

Project Fire is a flight-research program that is being conducted by the National Aeronautics and Space Administration to determine the total and radiative heat transfer at hyperbolic reentry speeds. As an aid in the selection of a suitable reentry configuration for Project Fire, the aerodynamic damping and oscillatory stability in pitch for two high-drag bodies of revolution have been experimentally determined at the Langley Research Center by using a forced-oscillation technique. Results obtained at Mach numbers from 0.60 to 1.20 at mean angles of attack from -4° to 14° are presented herein without detailed analysis.

SYMBOLS

The aerodynamic parameters are referred to the body system of axes originating at the oscillation centers of the models as shown in figure 1. The

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equations used to convert the dimensional aerodynamic coefficients of the model to the nondimensional aerodynamic parameters are presented in the section entitled "Reduction of Data." The symbols used herein are defined as follows:

A	reference area, $\pi\left(\frac{d}{2}\right)^2$, 0.559 sq ft
d	reference length, maximum diameter of model, 0.843 ft
k	reduced-frequency parameter, $\omega d/V$, radians
M	free-stream Mach number
q	angular pitching velocity, radians/sec
q_∞	free-stream dynamic pressure, lb/sq ft
R	Reynolds number based on d
V	free-stream velocity, ft/sec
α	mean angle of attack (angle of attack of equilibrium position of body center line), deg or radians
ω	angular velocity, 2π (Frequency of oscillation), radians/sec
C_m	pitching-moment coefficient, $\dfrac{\text{Pitching moment}}{q_\infty A d}$

$C_{m_\alpha} = \dfrac{\partial C_m}{\partial \alpha}$, per radian

$C_{m_q} = \dfrac{\partial C_m}{\partial\left(\frac{qd}{V}\right)}$, per radian

$C_{m_{\dot\alpha}} = \dfrac{\partial C_m}{\partial\left(\frac{\dot\alpha d}{V}\right)}$, per radian

$C_{m_{\dot q}} = \dfrac{\partial C_m}{\partial\left(\frac{\dot q d^2}{V^2}\right)}$, per radian

$C_{m_q} + C_{m_{\dot\alpha}}$ damping-in-pitch parameter, per radian

$C_{m_\alpha} - k^2 C_{m_{\dot{q}}}$ oscillatory-longitudinal-stability parameter, per radian

A dot over a quantity denotes a derivative with respect to time.

MODELS AND TUNNEL

Design dimensions of the two models tested are presented in figure 1. Photographs of the models mounted on the oscillation balance in the wind tunnel are presented as figure 2. The axially symmetric models have aluminum forebodies and fiberglass and Hetron afterbodies. The model surfaces exposed to the airstream are aerodynamically smooth.

Tests were made in the Langley 8-foot transonic pressure tunnel, which is a single-return, closed-circuit wind tunnel. The upper and lower walls of the test section are slotted to permit continuous operation through the transonic speed range. The Mach number in the test section can be continuously varied from a low subsonic value to 1.20. The sting-support system is so designed as to keep the center of oscillation of the model near the center line of the tunnel through a range of angle of attack from -4° to 14° when used in conjunction with the oscillating balance mechanism.

APPARATUS AND PROCEUDRE

The models are mounted on an oscillation balance, which is forced to perform an essentially sinusoidal, single-degree-of-freedom motion of about 2° amplitude by a motor-driven crank and Scotch-yoke arrangement. Accurate control of oscillation frequencies can be maintained from about 2 to 25 cycles per second. A detailed description of the oscillation mechanism is given in reference 1.

Dynamic data are obtained from the oscillation balance by alternating-current strain-gage bridges that sense the instantaneous torque required to drive the model and the instantaneous angular displacement of the model with respect to the sting. These strain-gage bridges modulate 3,000-cycle carrier voltages, which are passed through coupled electrical sine-cosine resolvers that rotate at the frequency of oscillation of the model. The resolvers resolve the signals into orthogonal components, which are then demodulated and read on damped digital voltmeters. By responding only to signals at the fundamental frequency of oscillation, the resolver and damped-voltmeter system performs the desirable function of eliminating the effects of random torque inputs due to airstream turbulence or buffeting. The maximum torque required to drive the model, the maximum displacement of the model with respect to the sting, and the phase angle between the torque and displacement are found from the orthogonal components of torque and displacement. The frequency of oscillation is obtained by counting the pulses generated by an induction-coil pickup and 100-tooth gear fastened to the shaft of one of the resolvers. The damping and spring-inertia characteristics of the oscillating system are then computed from the measured values of torque, displacement, phase angle, and frequency.

All data were taken with the model oscillating near its velocity-resonant frequency, inasmuch as this condition assures the most accurate determination of the system damping coefficient and spring-inertia characteristic.

REDUCTION OF DATA

For these tests, measurements were made of the maximum applied pitching moment M_Y, the maximum angular displacement in pitch of the model with respect to the sting Θ, the phase angle η between M_Y and Θ, and the angular velocity of the forced oscillation ω. As explained in detail in reference 2, the viscous damping coefficient for this single-degree-of-freedom system can be computed as

$$C_Y = \frac{M_Y \sin \eta}{\omega\Theta} \tag{1}$$

and the spring-inertia characteristic can be computed as

$$K_Y - I_Y\omega^2 = \frac{M_Y \cos \eta}{\Theta} \tag{2}$$

where K_Y is the torsional spring coefficient of the system and I_Y is the moment-of-inertia coefficient of the system about the body Y-axis (pitching axis). The damping-in-pitch parameter was computed as

$$C_{m_q} + C_{m_{\dot{\alpha}}} = -\frac{V}{q_\infty Ad^2}\left[\left(\frac{M_Y \sin \eta}{\omega\Theta}\right)_{\text{wind on}} - \left(\frac{M_Y \sin \eta}{\omega\Theta}\right)_{\text{wind off}}\right] \tag{3}$$

and the oscillatory-longitudinal-stability parameter was computed as

$$C_{m_\alpha} - k^2C_{m_{\dot{q}}} = -\frac{1}{q_\infty Ad}\left[\left(\frac{M_Y \cos \eta}{\Theta}\right)_{\text{wind on}} - \left(\frac{M_Y \cos \eta}{\Theta}\right)_{\text{wind off}}\right] \tag{4}$$

The wind-off value of $\frac{M_Y \sin \eta}{\omega\Theta}$ was determined at the frequency of wind-off velocity resonance. The wind-off and wind-on values of $\frac{M_Y \cos \eta}{\Theta}$ were determine at the same value of ω^2.

A factor of 2, which is conventional for winged bodies, does not appear in equation (3), inasmuch as the reduced-frequency parameter is defined as $k = \frac{\omega d}{V}$ for bodies of revolution instead of $k = \frac{\omega d}{2V}$.

TESTS AND PRESENTATION OF DATA

The tests were made at Mach numbers from 0.60 to 1.20 and at Reynolds numbers, based on the maximum diameter of the model, from 1.75×10^6 to 3.50×10^6. The mean angle of attack α was varied from -4° to 14°. The amplitude of the forced oscillation was about 2°.

The damping-in-pitch parameter $C_{m_q} + C_{m_{\dot{\alpha}}}$, the oscillatory-longitudinal-stability parameter $C_{m_\alpha} - k^2 C_{m_{\dot{q}}}$, and the reduced-frequency parameter k for the two configurations are presented graphically in figure 3 as functions of mean angle of attack α for the different test Mach numbers. Positive damping and stability are indicated by negative values of the damping-in-pitch and oscillatory-longitudinal-stability parameters.

SUMMARY OF RESULTS

The results presented in figure 3 indicate that near $\alpha = 0^\circ$, both configurations had negative damping in pitch. Away from $\alpha = 0^\circ$ both configurations had nearly zero damping at a Mach number of 0.60 and slightly positive damping at the higher Mach numbers. The trends and levels of damping in pitch were similar for both configurations. The decrease in damping noted in regions of increasing stability is characteristic of bodies of this general shape.

Both configurations had almost constant positive oscillatory stability over the α-range of the same magnitude except at $M = 0.60$, for which configuration 1 was more stable than configuration 2 at the same Reynolds number. A decrease in Reynolds number for configuration 1 decreased its stability to the same level as that obtained with configuration 2 at the higher Reynolds number. No explanation can be offered for the anomalous effect of Reynolds number on the oscillatory stability characteristics. The effect of decreasing Reynolds number was not investigated at the higher Mach numbers. The limited Reynolds number data, however, emphasize the need for simulating full-scale flow conditions as closely as possible if meaningful experimental results are to be obtained in the wind tunnel.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., July 9, 1963.

REFERENCES

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2. Braslow, Albert L., Wiley, Harleth G., and Lee, Cullen Q.: A Rigidly Forced Oscillation System for Measuring Dynamic-Stability Parameters in Transonic and Supersonic Wind Tunnels. NASA TN D-1231, 1962. (Supersedes NACA RM L58A28.)

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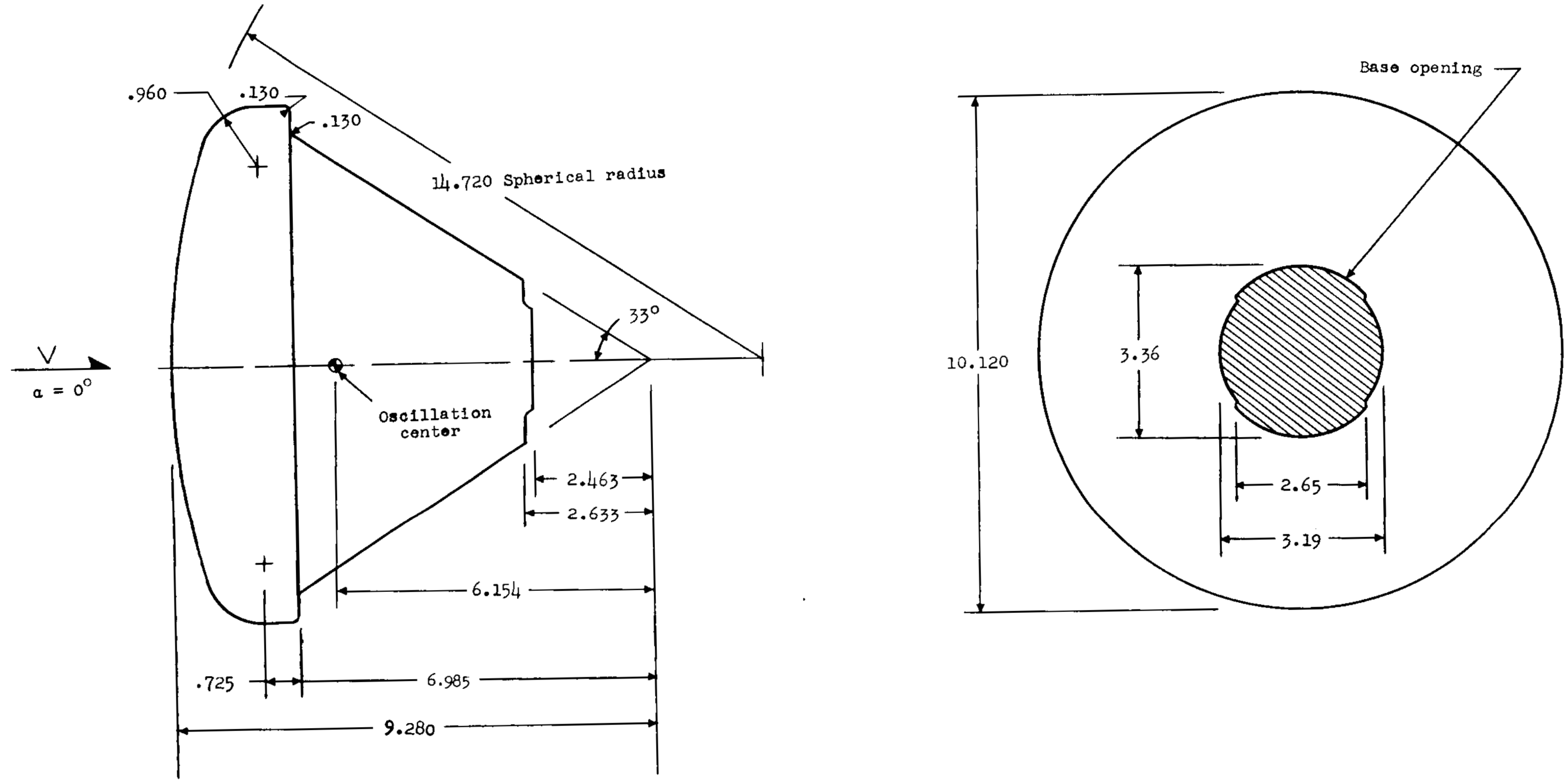

(a) Configuration 1.

Figure 1.- Design dimensions of the models. All linear dimensions are in inches.

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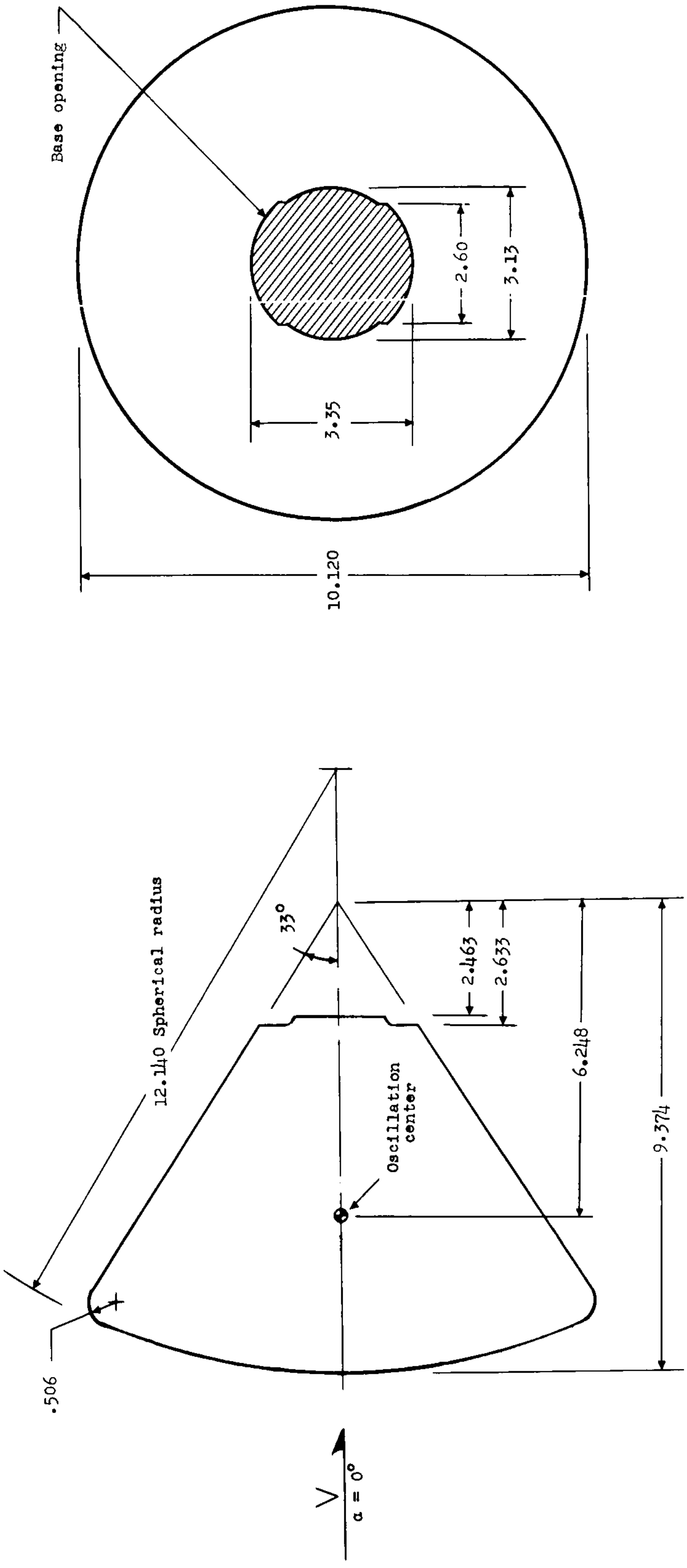
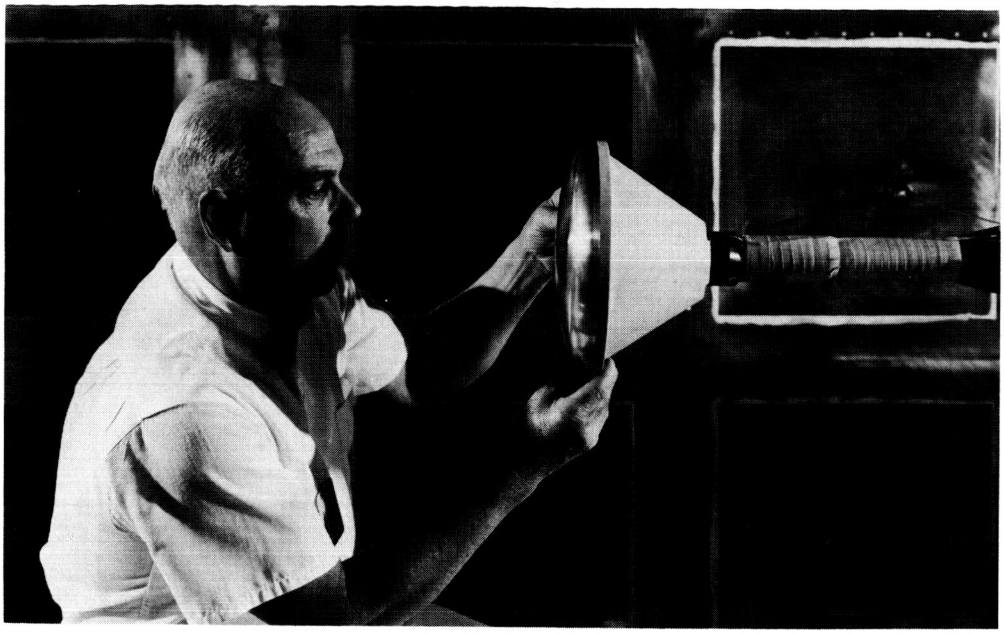


(b) Configuration 2.

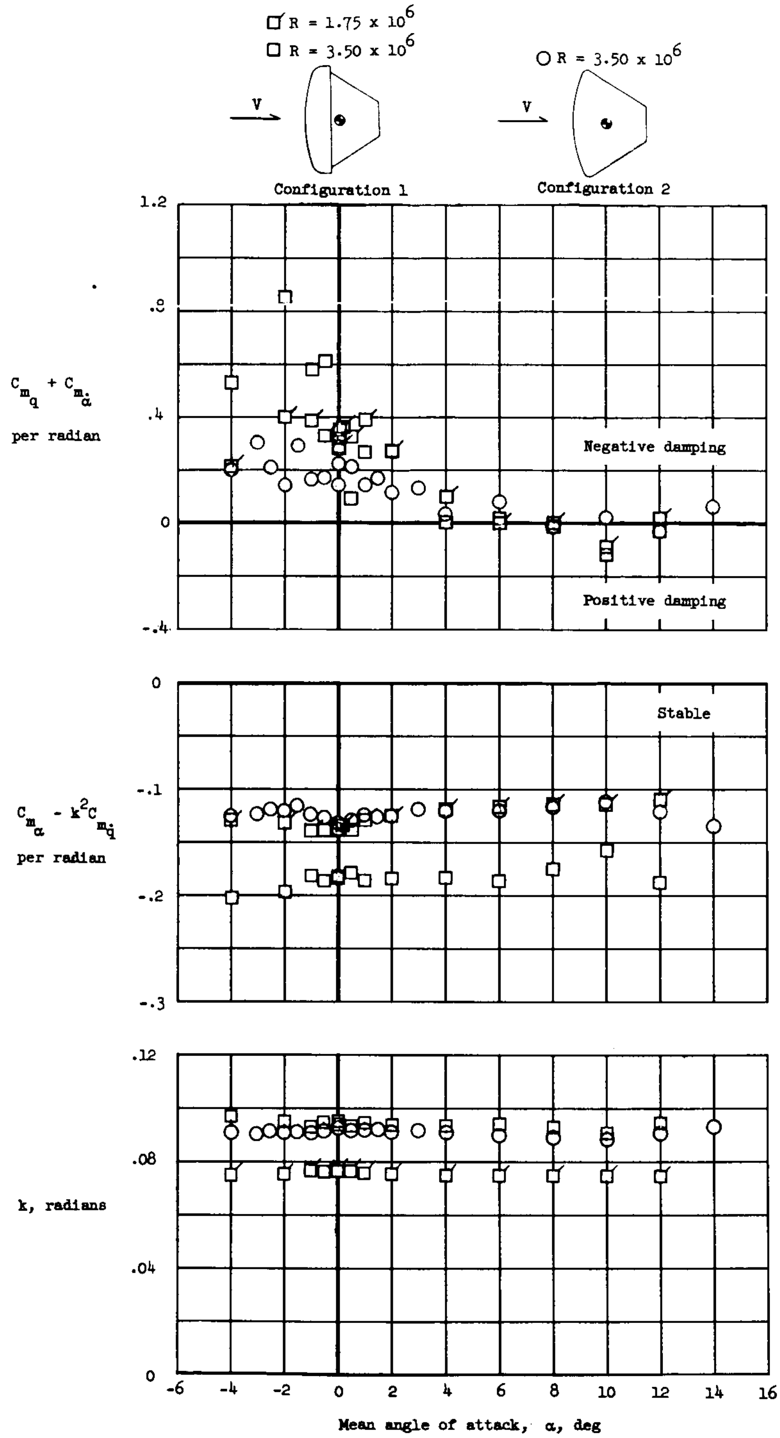
Figure 1.- Concluded.



(a) Configuration 1. L-62-3637

(b) Configuration 2. L-62-3636

Figure 2.- Photographs of models in Langley 8-foot transonic pressure tunnel.



(a) M = 0.60.

Figure 3.- Variation of damping-in-pitch parameter, oscillatory-longitudinal-stability parameter, and reduced-frequency parameter with mean angle of attack α for two high-drag bodies of revolution.

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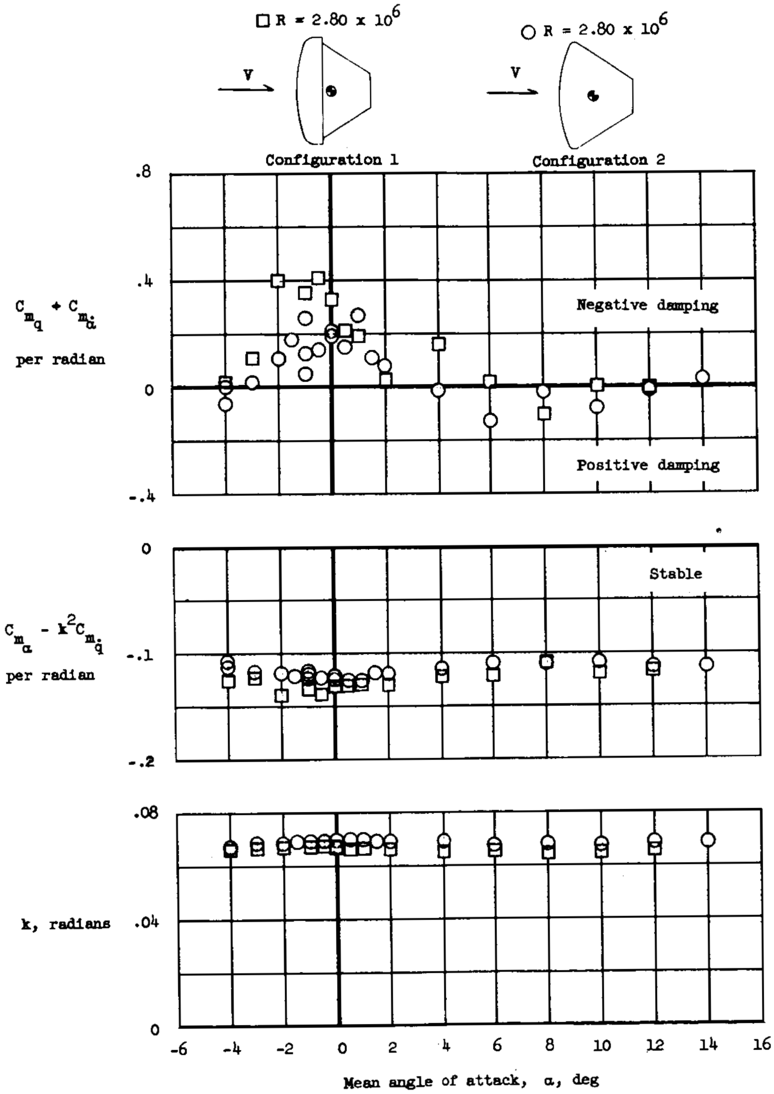

(b) M = 0.80.

Figure 3.- Continued.

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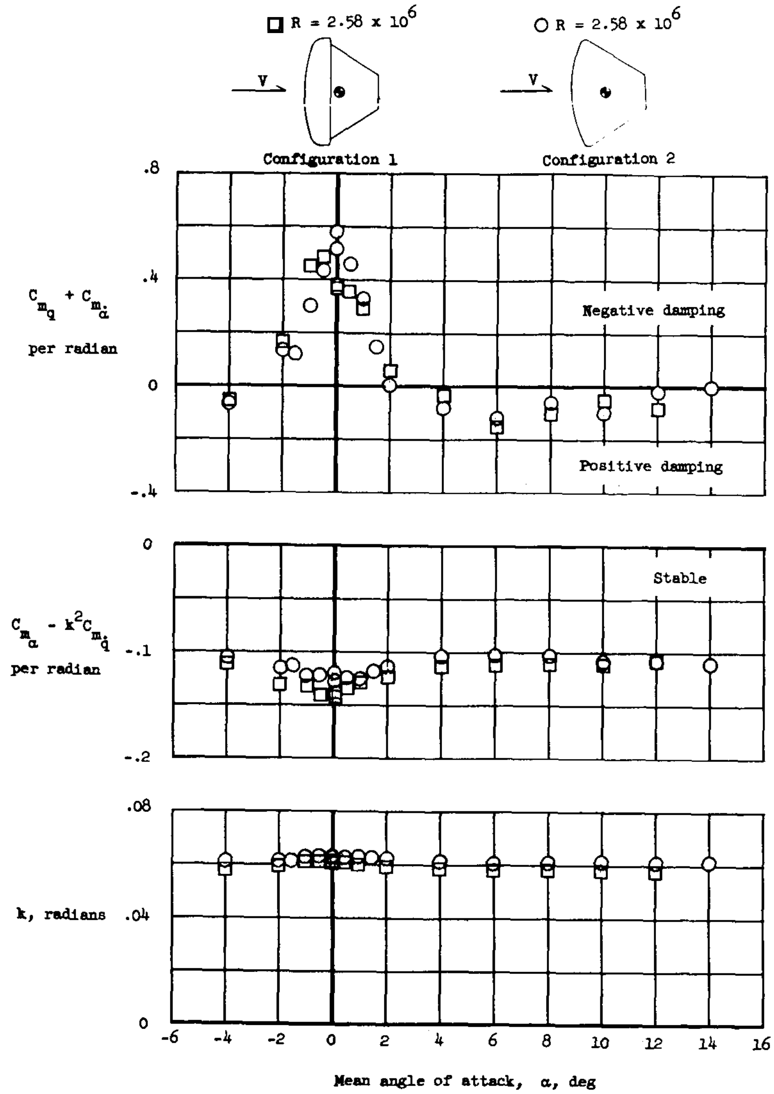
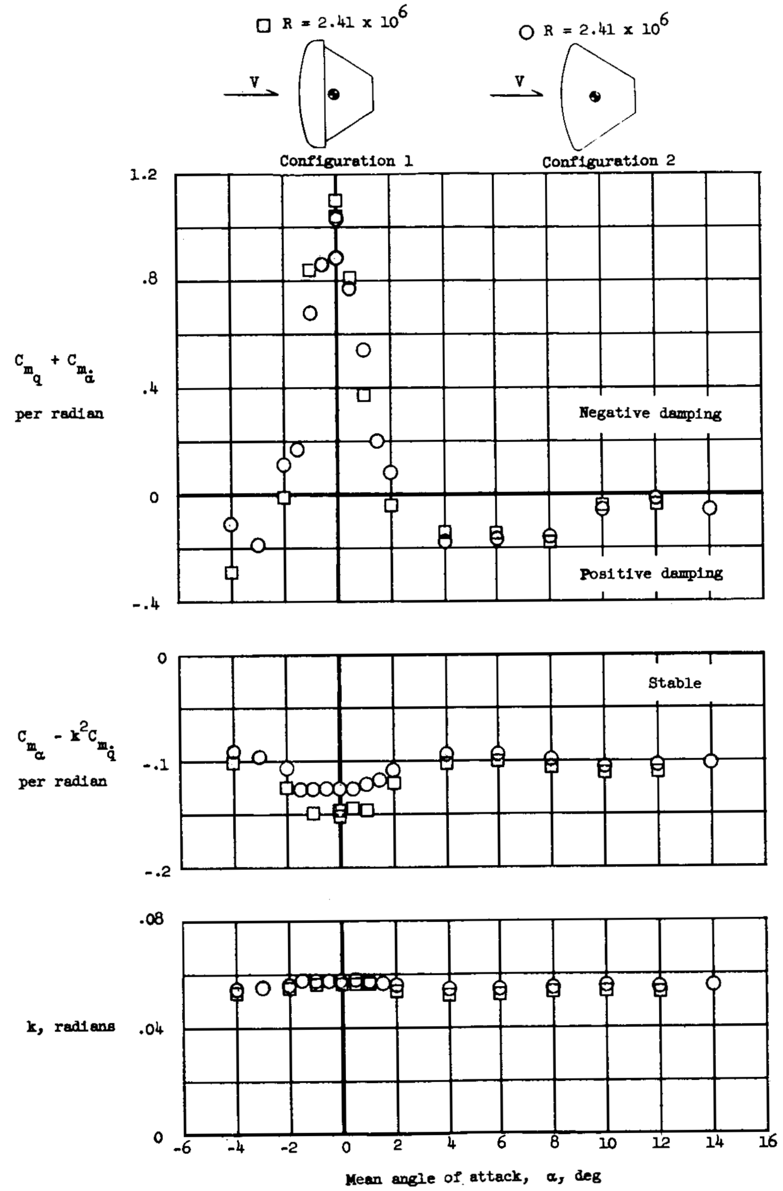


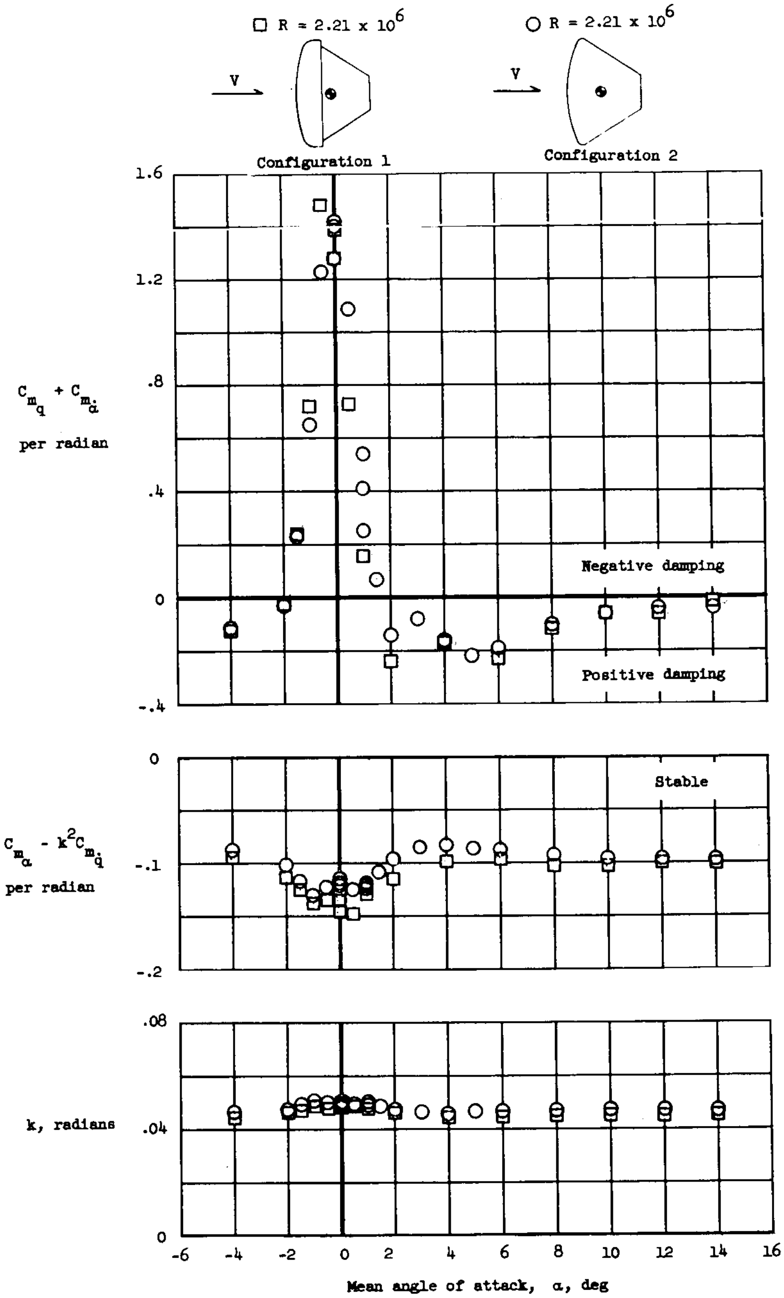
(c) M = 0.90.

Figure 3.- Continued.



(d) M = 1.00.

Figure 3.- Continued.



(e) M = 1.20.

Figure 3.- Concluded.